



SMAC/SMAD Review Agenda

Shape Memory Alloy Consortium (SMAC)

Shape Memory Alloy Development (SMAD)

June 26, 2000

SMAC/SMAD

- **DARPA System Overview Charts**
- **Participants Summary**
- **SMAC Program Summary**

Dean Jacot

dean.jacot@boeing.com

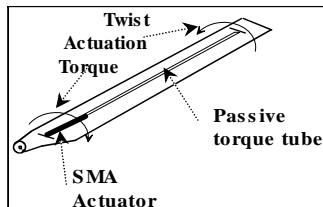
-
- **SMAD Objectives**
 - **SMAD Effort Tasks**
 - Requirements, Concepts, Actuator, Thermal
 - **SMAD Program Summary**

SMA Consortium (SMAC) Objectives

SMAC

SMAC Objectives & Scope

- Characterization of Existing SMA Materials



SMA Concept

- Develop Nickel Free Titanium (NFT) SMA
- Development of Ferromagnetic SMA

Ended
Oct
1999

SMAC/SMAD Objectives

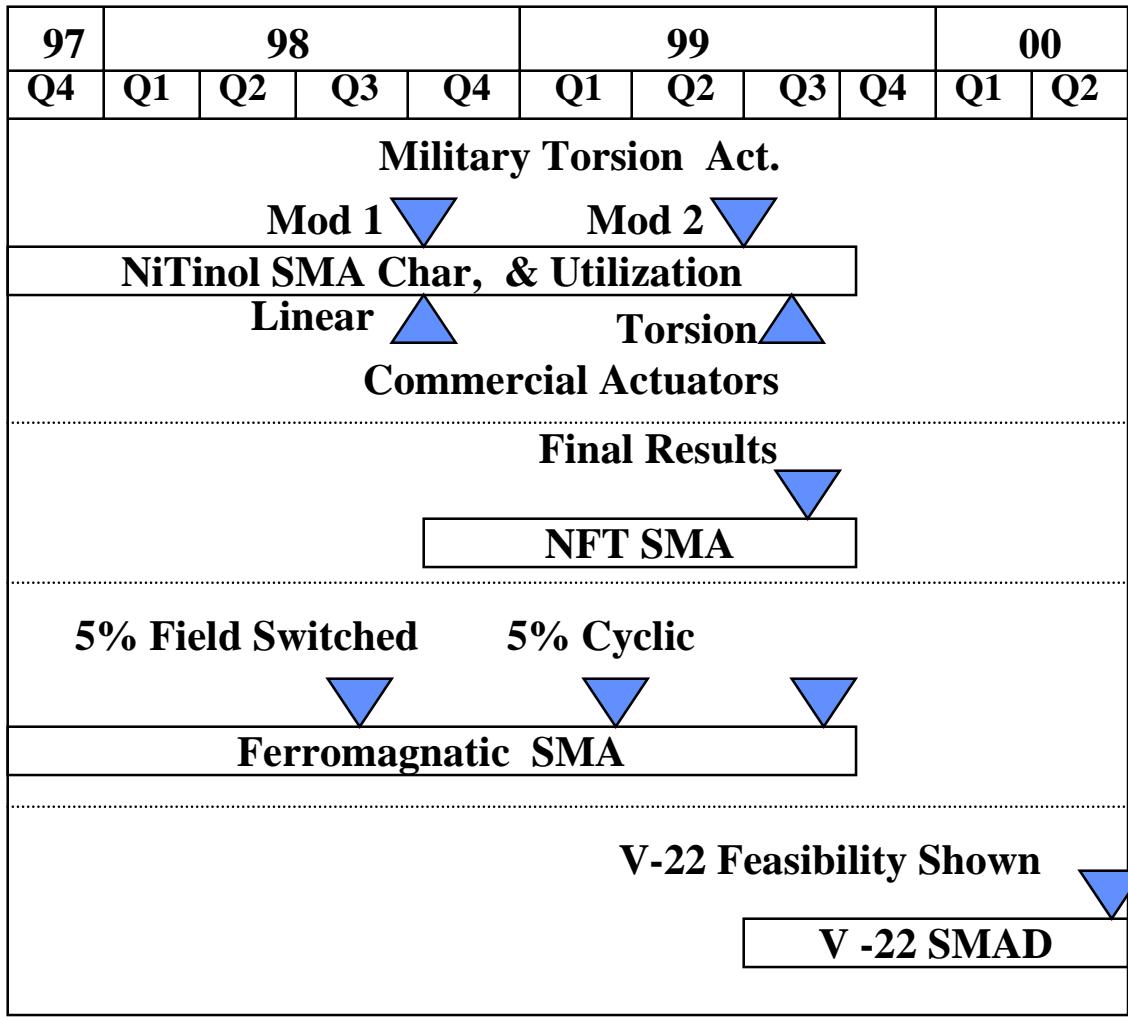
- Show feasibility of V-22 SMA torsional actuation System

Rationale

- Characterize NiTi materials
 - Torsion & Fatigue
- Develop torsional actuators
- Develop commercial actuators
- Potentially lighter weight and higher temp
- Energized by magnetic field
 - Higher speed (vs thermally)
 - Higher power density material
- Feasibility shown



SMAC Schedule



SMAC

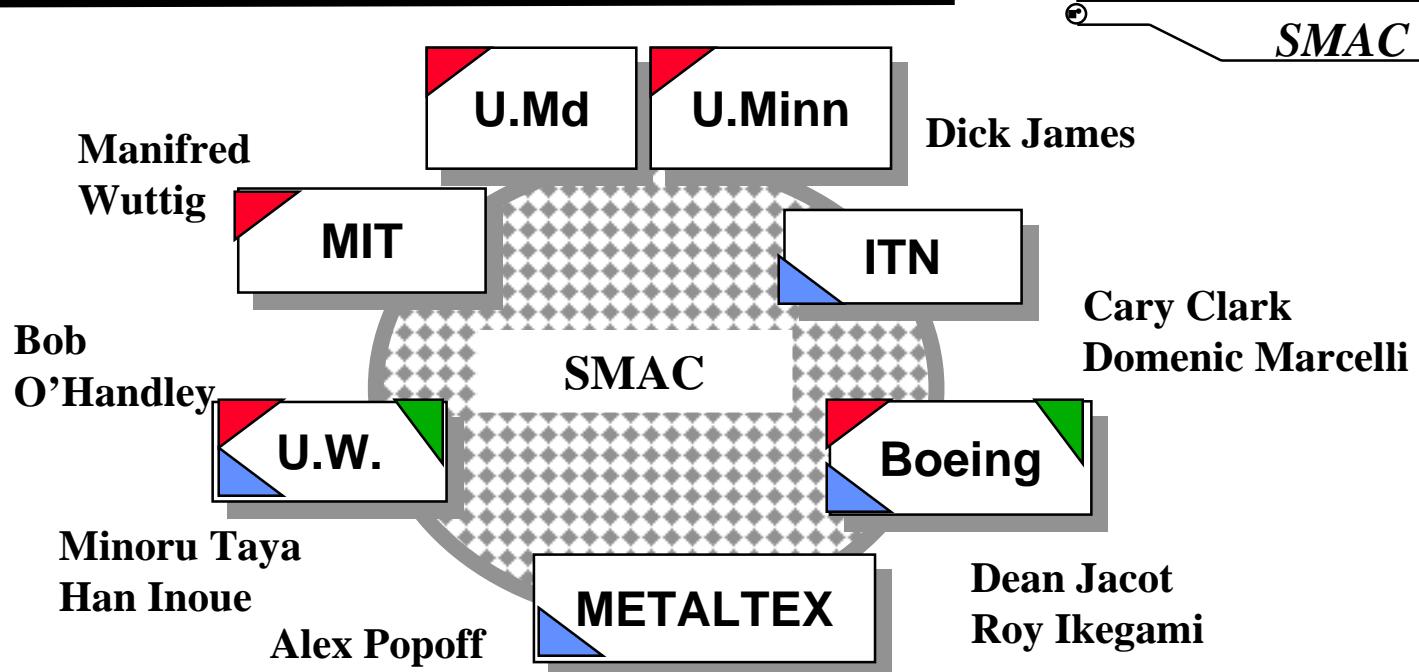
- **SMAC Final Review Held 10/99 (No open items)**
- **Basic SMAC Final Report Submitted 2/00**
- **Incremental Review 2/00**
- **Final Review Today**



Tasks & Organizations

SMA Consortium (SMAC)

DARPA
W. Coblenz
E. Garcia
ONR
R. Barsoum



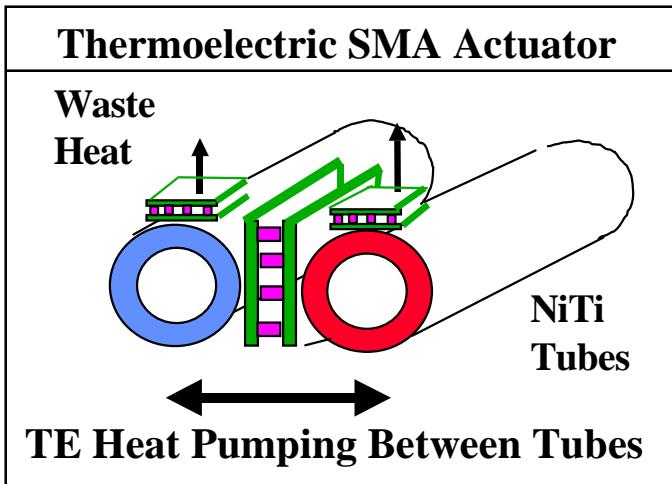
SMAC Tasks

- 1 NiTinol SMA
- 2 Nickel Free Titanium SMA
- 3 Ferromagnetic SMA

Participant Major Contribution

- Boeing - Military Torsion Actuator
- ITN - Commercial Actuators
- MetalTex - Materials
- UW - Isothermal FSMA
- MIT/U.Md- Variant Redistribution /U.Minn FSMA

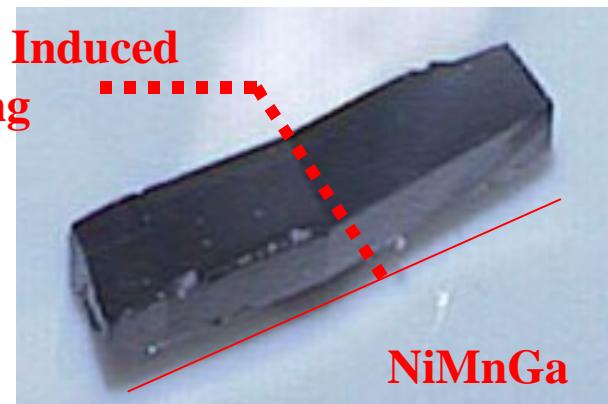
“Basic” SMAC Accomplishments



Other Accomplishments

- NiTinol fatigue data
- TMP& Cold Work Characterization
- Commercial Actuators

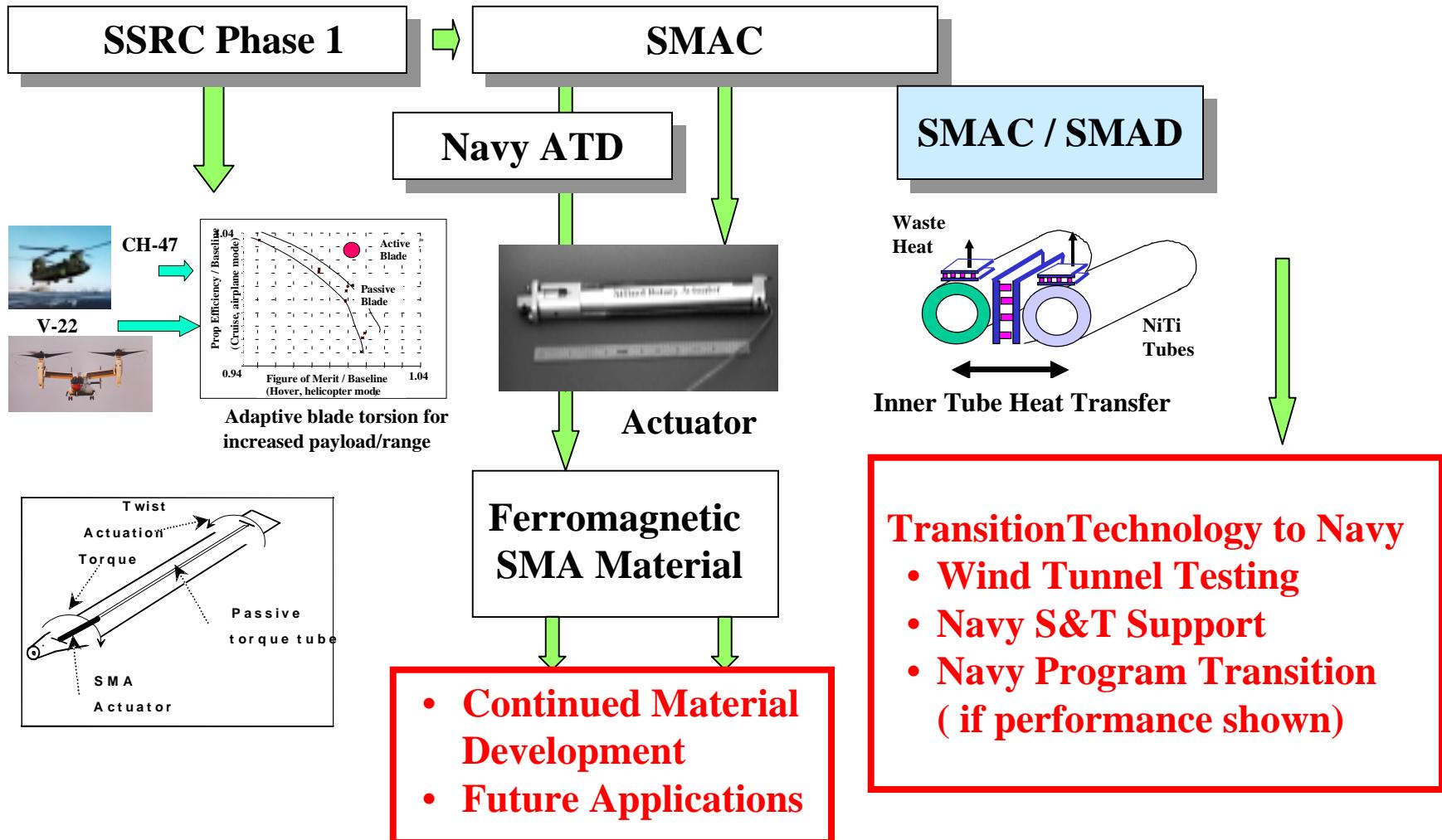
5% Cyclic Strain
Ferromagnetic SMA
Demonstrated



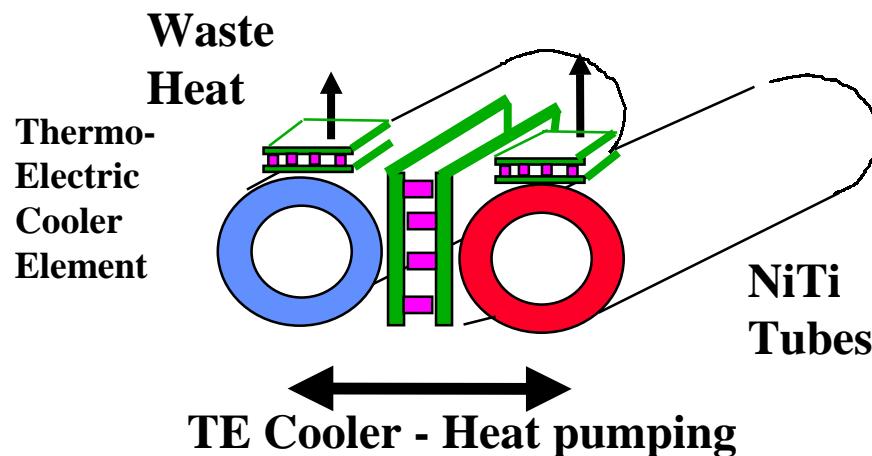
SMAC Program Value & Customers

SMAC/SMAD

95	96	97	98	99	00
----	----	----	----	----	----



Boeing SMAC Summary

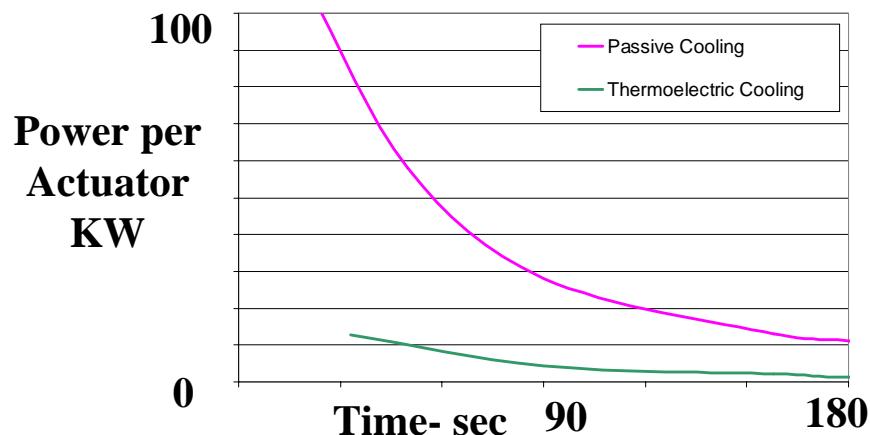


SMAC

Thermal SMA Actuator



Power- Response Capability



NiTinol Application Technology

- Heat Treatment & Processing
- Characterization
- Termination
- Control
- Locks



MetalTex SMAC Contribution Summary

SMAC

- ▶ Clean and Homogeneous SME and SE NiTi Alloys -- to enhance fatigue life.
- ▶ Two SME and one SE Alloys.
- ▶ Torsion fatigue tubular test samples: 95 ea.
- ▶ Tensile test samples: 105 ea.
- ▶ Subscale strained tubular specimens: 12 ea.
- ▶ Full-scale SME prototype strained torsion tube.
- ▶ Make available proprietary TMP processing as straining mechanism to complement or replace cold working.
- ▶ Consulted on testing procedures.
- ▶ Identified manufacturing approach for production torsion tubes.

October 22, 1999

MetalTex International

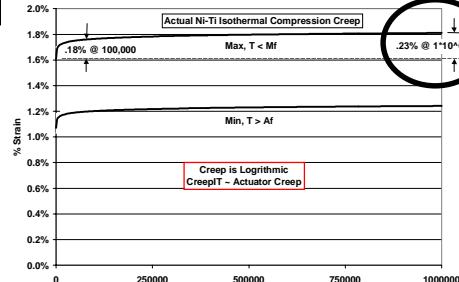




SMAC - ITN Major

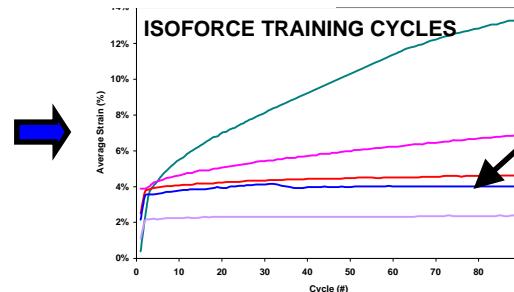
Accomplishments

ACCURATE & QUICK
SMA FATIGUE LIFE
PREDICTION METHOD



ISOHERMAL
FATIGUE RESULTS
GIVE ACCURATE
PREDICTION OF
ACTUATOR CREEP

OPTIMIZATION TECHNIQUES
TO MAXIMIZE ACTUATOR
WORK AND MINIMIZE CREEP



OPTIMAL HEAT
TREAT, TRAINING
AND CONDITIONING
GIVES OPTIMAL
STROKE AND CREEP

SMA ACTUATOR DESIGN TOOLS

TESTING DATABASE
THERMAL RESPONSE
MECHANICAL PROPERTIES
CYCLE LIFE

ANALYSIS
THERMAL RESPONSE
MECHANICAL RESPONSE
TERMINATIONS
CYCLE LIFE

DESIGNED & BUILT
TWO OPTIMIZED
COMMERCIAL SMA
ACTUATORS

LINEAR
ELECTRALOCK
ACTUATOR

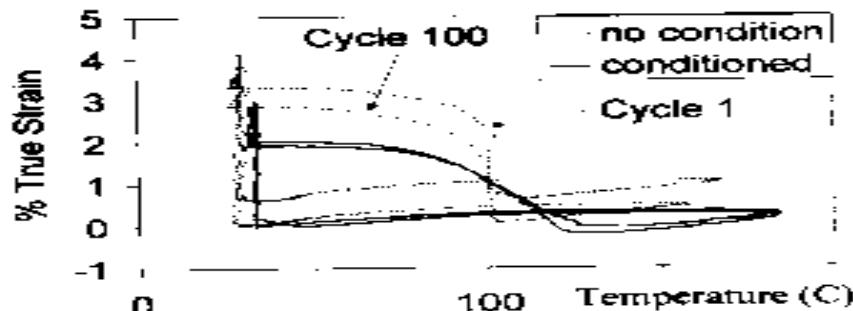


TORSIONAL
CLAMP
ACTUATOR



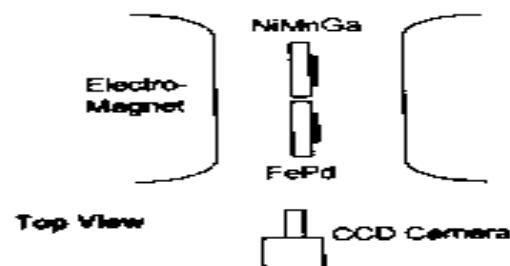
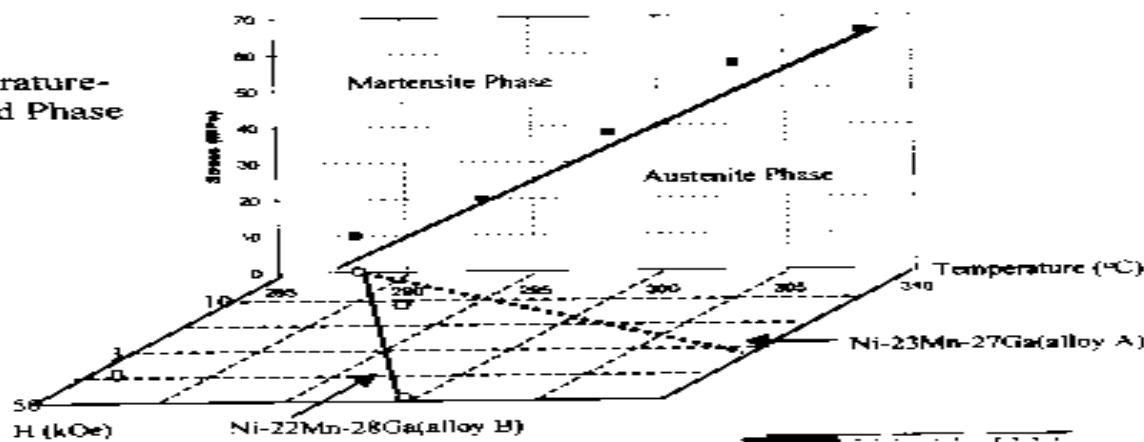
Thermomechanical Shape Memory Alloy (SMA)

Strain of TiNi under Thermal Actuation



Ferromagnetic SMA

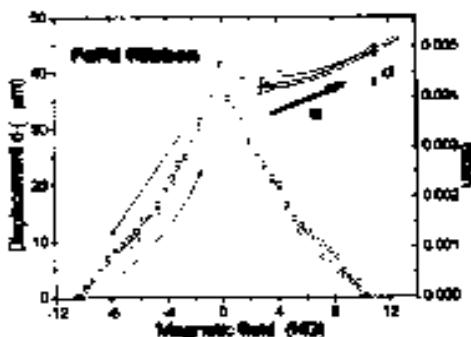
Stress-Temperature-Magnetic field Phase Diagram





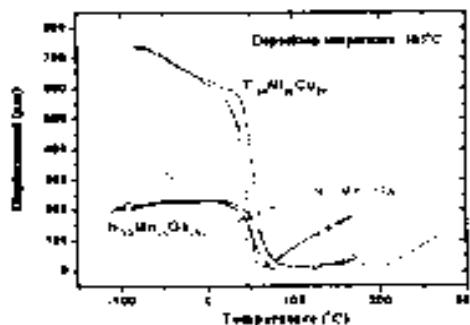
Research Highlights

Identified the Fe-Pd alloy system



Hysteresisfree
actuation material

Prepared NiMnG films



Thermomagnetically
actuated flow control
devices,
sensors

Identified search
algorithm for new
MSMAs



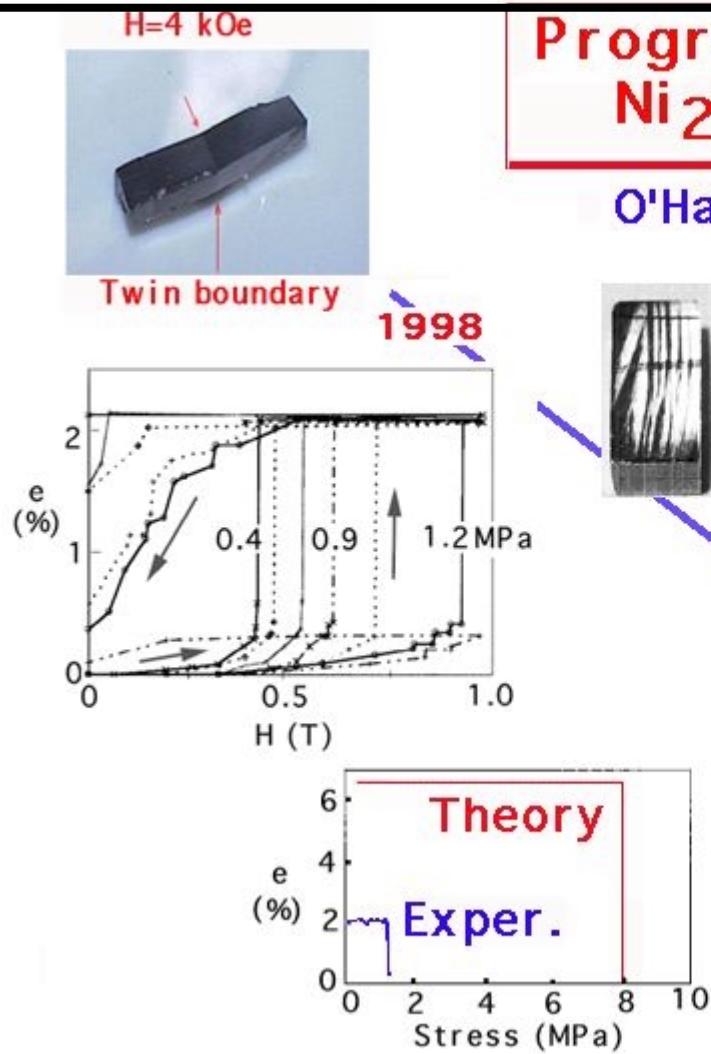
Future Applications

Ferromagnetic Shape Memory

1. Measurement of largest strain vs. magnetic field in “actuator configuration”: 2.5%. Measurement of 5% bulk strain from the field cooled state.
2. A method of growth of large single crystals of Fe_3Pd alloy with uniform composition. A heat treatment that raises the transformation temperature of Fe_3Pd to above room temperature.
3. A quantitative theory of the ferromagnetic shape memory effect, leading to:
 - a) A strategy for searching for new ferromagnetic shape memory materials based on high anisotropy and mobile twin boundaries.
 - b) Tools for actuator design and textured composite design
 - c) Prediction (and experimental verification) of shape effect.
 - d) A predictive understanding of the ferromagnetic shape memory effect.
4. A method for measuring anisotropy constants of single variant martensite (This is the most important measurement for screening new alloys).
5. A unique magnetomechanical testing machine adapted to studies of ferromagnetic shape memory for actuator applications.



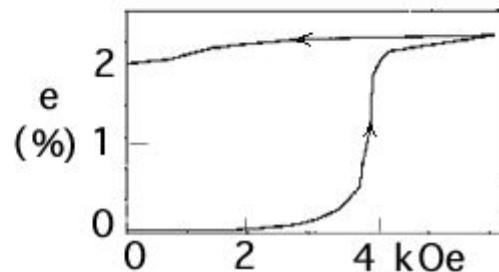
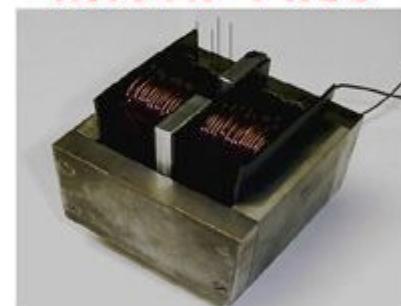
Main MIT Accomplishments



Progress in high-strain Ni_2MnGa actuators

O'Handley, Allen, M.I.T.

2% (6%) strain
R.T. in 4 kOe

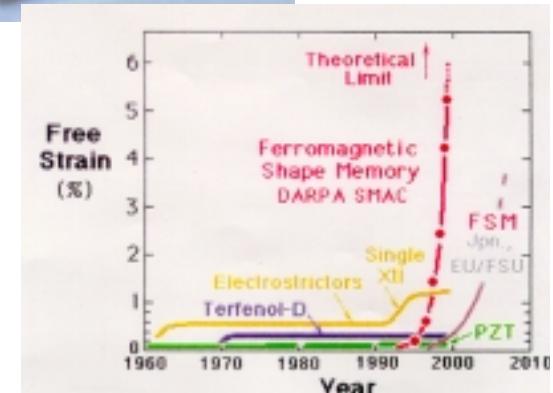
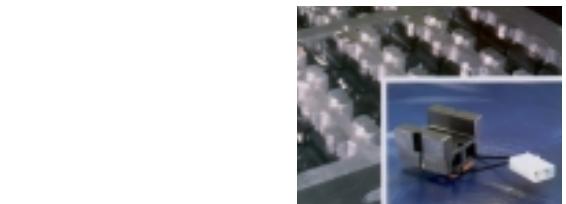
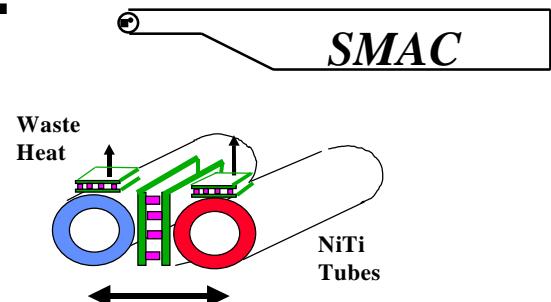


SMAC Program Summary

SMAC has been a very successful program

- Actuators, Materials, Cooperation

- Thermoelectric SMA Actuator
 - TE Heat Pumping Between Elements
- Linear & Torsional Commercial Actuators
- NiTinol Testing Methods & Fatigue data
- TMP & Cold Work Characterization
- 5 % Cyclic Strain Ferromagnetic SMA (FSMA)
- Understanding of FSMA (i.e., shape effects)
- Evaluation of Numerous FSMA alloys





SMAC/SMAD Review Agenda

SMAC/SMAD

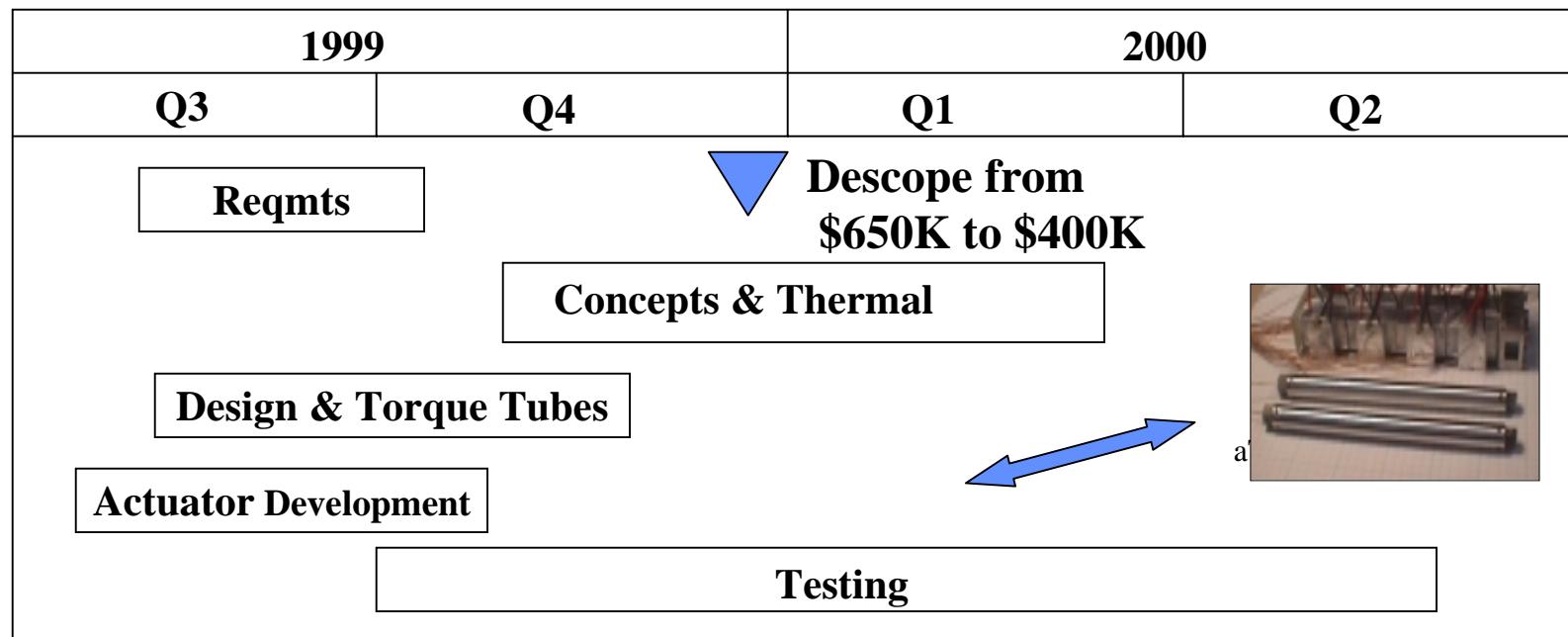
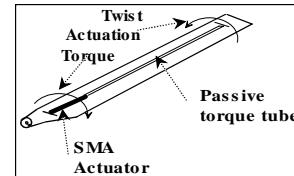
- **SMAD Objectives**
- **SMAD Effort Task Summaries**
- **Requirements, Concepts, Actuator, Thermal**
- **SMAD Program Summary**



SMAC/ SMAD Program

SMAC / SMAD Objectives

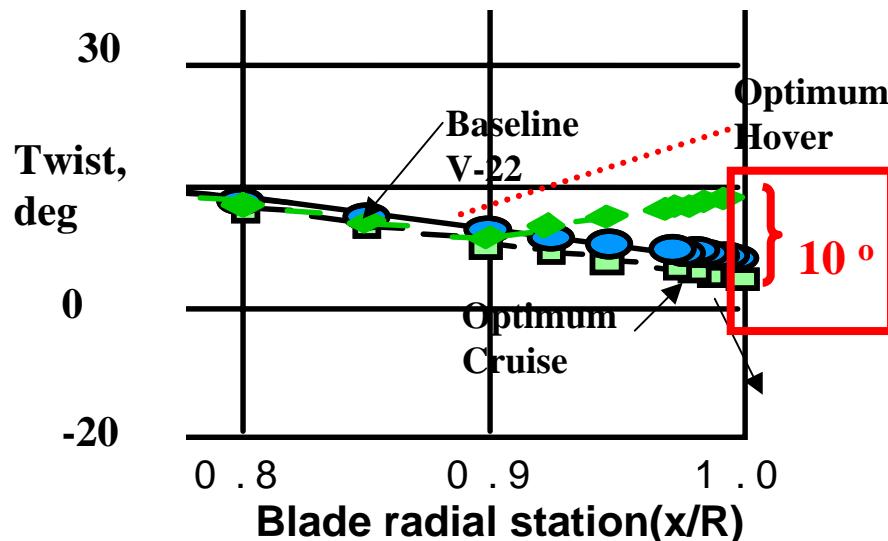
- Prove feasibility and practicality of SMA actuator for V-22 blade twist
 - Requirements & Benefits
 - Actuation Concepts Trades
 - Actuator Design Trades
 - Thermal Modeling
 - Passive Torque Tube



a

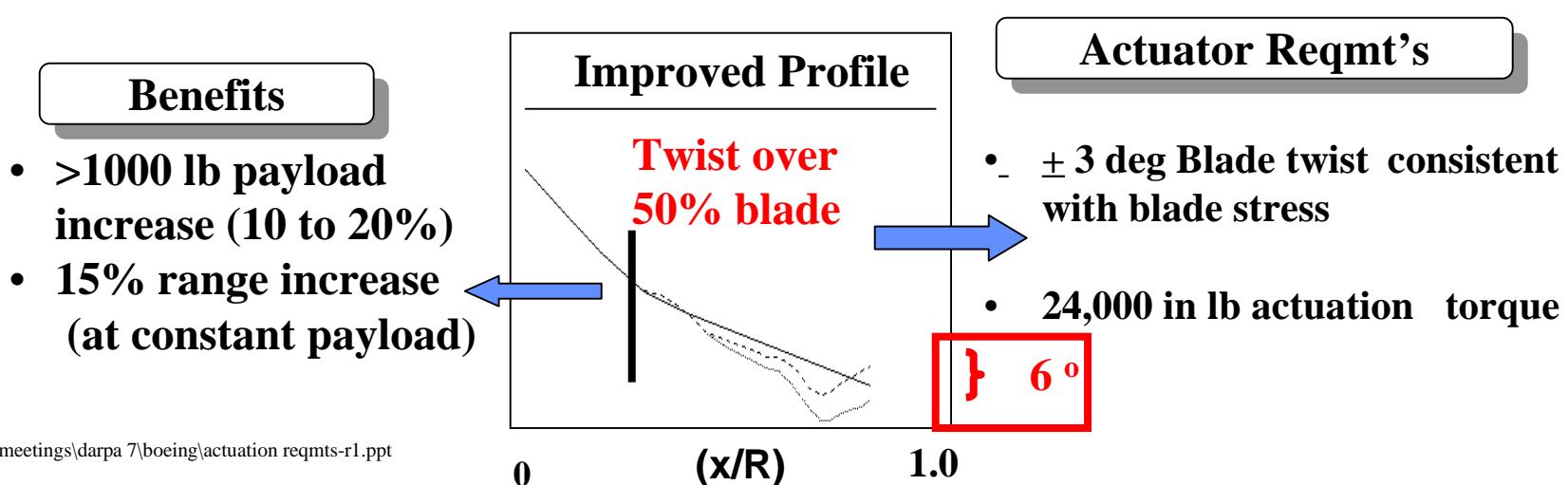


Actuation Requirements & Benefits



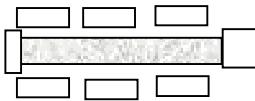
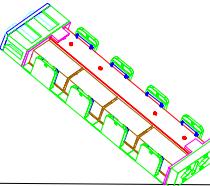
SMAC/SMAD

- Initial actuator location at 90% X/R
 - Packaging difficulty
 - Blade stability
- Elliptical torque tube solves passive torque tube packaging
- Dual passive torque tubes allows tip twist with actuator at blade center

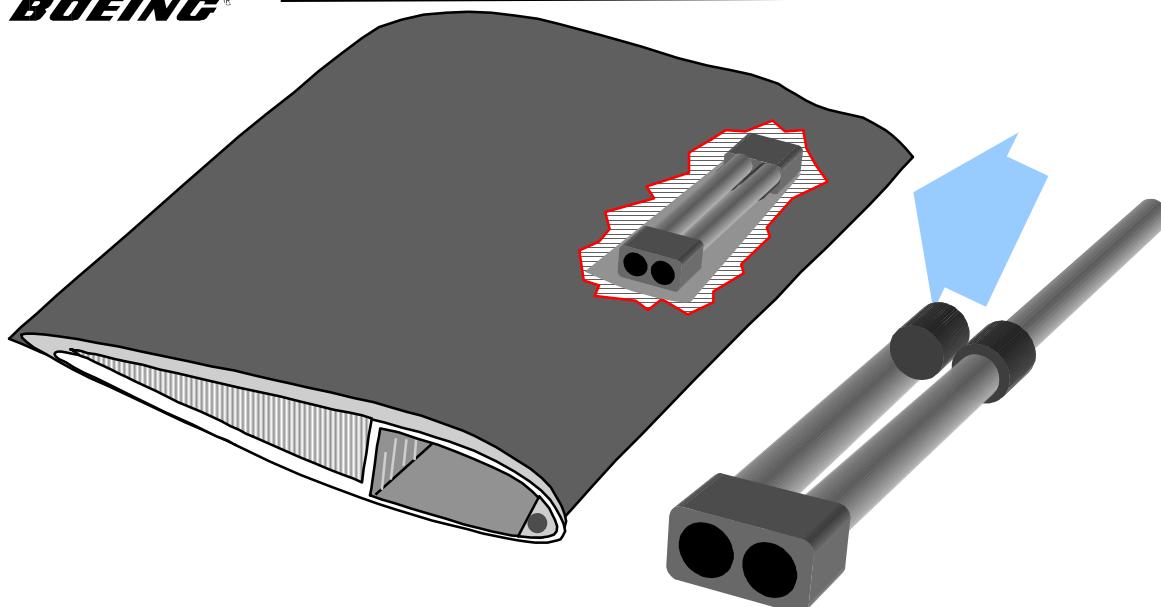


Actuator Concepts & Preliminary Assessment

SMAC/SMAD

Concept		Length (inch)	Time -sec @ 2KW	Complexity	Weight (lbs)
Single- TEM		33	180	Moderate	34.9
	Single - Heater	33	1000	Low	28.3
Bi-axial		23	170	Moderate	38.97
Coaxial TEM		29	90	Moderate	38.7
Coaxial (Heater long)		23	500	Low	25.27
coaxial-longitudinal TEM		23	500	Moderate	35.97
Mechanical heat switch		33	(180)	High	37.3

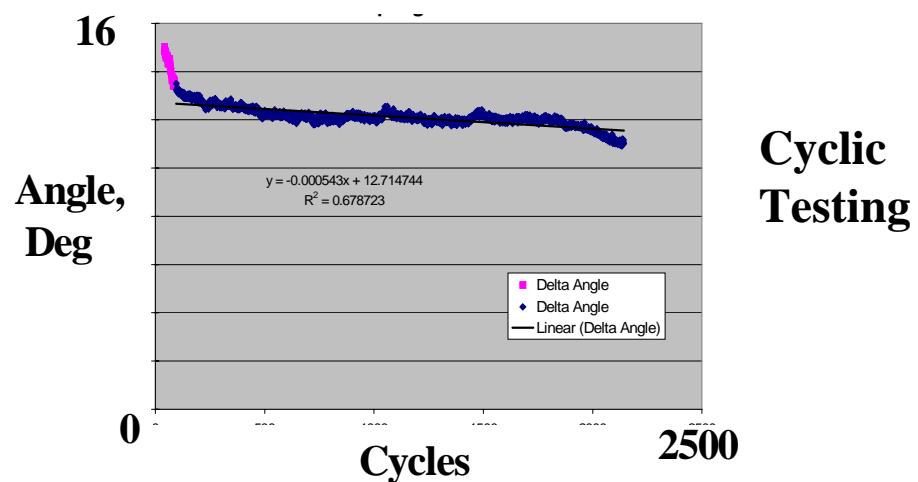
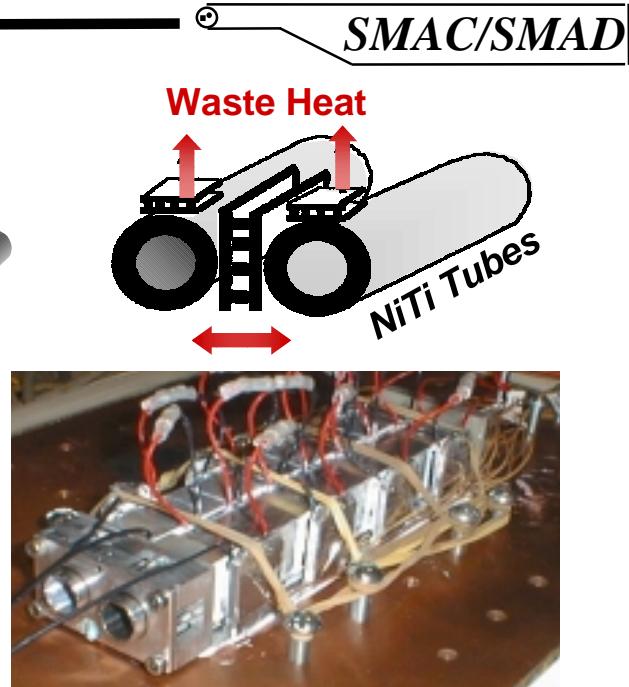
SMA Actuator Concept & Testing



**Antagonistic
Torque Tubes
(Gear Coupled)**

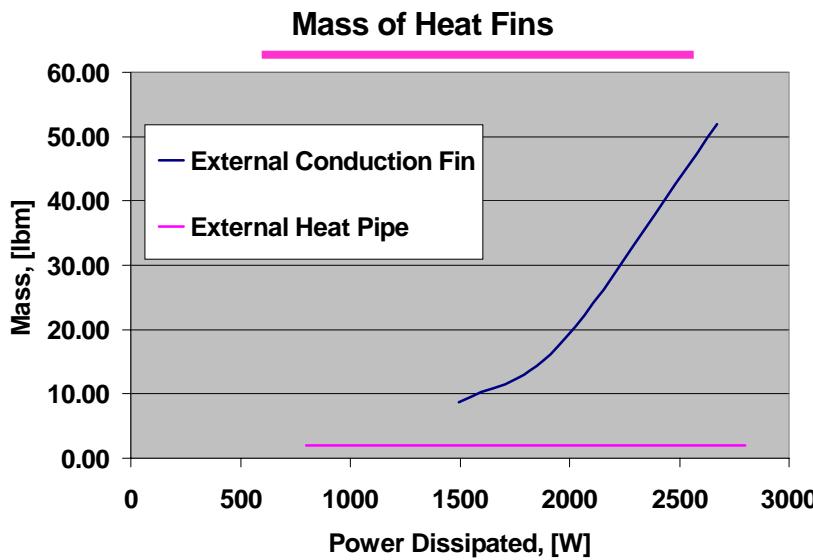
Advantages

- Can achieve fast response (i.e., 40 sec. at 12 Kw)
- Less overall power requirements
- Less waste heat

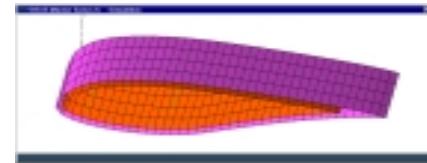


External Heat Exchange Approaches

- Thermal Models and Design Tools Have Been Developed
 - Actuator
 - Resistive & TEM heating/cooling
 - Heat exchanger to air
 - Airfoil heat transfer coefficients

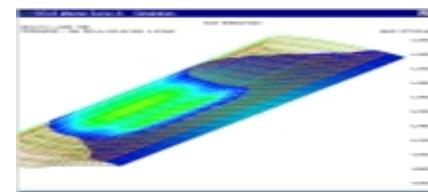
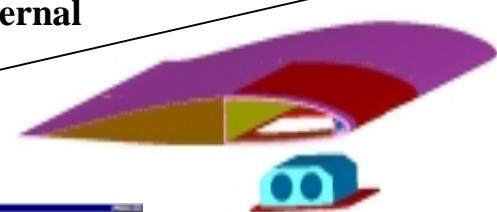


SMAC/SMAD



Internal All-Metal Heat Fin Without Door

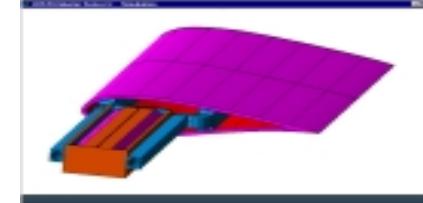
Internal & External Heat Fins



Temps For Door (External Fin)

Single Metal Door Configuration (External Fin Group)

Heat Pipes Dissipate More Heat (Reduce ΔT)





SMAC/SMAD Program Summary

②

SMAC/SMAD

- New Actuation requirements identified with significant payoff
 - 1200 lbs payload or > 80 nm range at constant payload
- Feasible V-22 actuation SYSTEM identified
 - Bi -Axial actuator at 50% x/r
 - Stiff composite torque tubes
- Actuation concept trades initiated
- Overall Assessment of thermal problem developed
- Thermo-electric 1/4 scale Bi-axial SMA actuator developed
 - TE Heat pumping between NiTi tubes
 - Cyclic testing initiated